A hydraulic circuit includes a pump driven by a motor, an inverter for controlling the motor, and an accumulator. The inverter controls rotational speed of the motor such that the pump always discharges hydraulic fluid at a fixed flow rate, which is the sum of an average necessary flow rate and an adjustment flow rate. The accumulator operates, when the fixed flow rate and a necessary flow rate differ, in order to accumulate or discharge the hydraulic fluid to thereby secure the necessary flow rate.
HYDRAULIC CIRCUIT AND METHOD FOR CONTROLLING THE SAME

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a hydraulic circuit used for a machine tool or the like.

[0003] More particularly, the present invention relates to a hydraulic circuit which includes an accumulator and an inverter for controlling a pump, and to a method for controlling the same.

[0004] 2. Description of the Related Art

[0005] A conventional hydraulic circuit includes a pump and an accumulator. By means of controlling a motor of the pump, hydraulic fluid of a required quantity is supplied to the hydraulic circuit. When the supply of hydraulic fluid is unnecessary, the motor is turned off so as to save energy. However, in the case of a large motor, even when the motor is turned on, it does not reach a prescribed rotational speed immediately, and takes time to reach the prescribed rotational speed. In addition, if the motor is repeatedly turned on and off at short intervals, an electromagnetic switch for the motor becomes likely to break. Therefore, the above-described method for turning the motor on and off for energy saving is problematic.

[0006] In order to solve the problem of the conventional method, there has been employed a method of controlling the motor by means of an inverter instead of turning the motor on and off. This inverter controls the rotational speed of the motor on the basis of a pressure detected by a pressure sensor disposed in the hydraulic circuit.

[0007] The conventional method for controlling the motor by use of an inverter has the following problems.

[0008] (1) Even in the case where hydraulic fluid is not required to be supplied (flow rate is zero), the pressure sensor detects a drop in hydraulic pressure because of leakage of hydraulic fluid from the hydraulic circuit. Therefore, the inverter never turns the motor off, although it decreases the rotational speed of the motor.

[0009] (2) When the rotational speed of the motor is low; for example, equal to or less than 500 rpm, vibration is generated because of knocking, which hinders operation.

SUMMARY OF THE INVENTION

[0010] In view of the foregoing, an object of the present invention is to save energy without hindering operation.

[0011] An aspect of the present invention provides a hydraulic circuit which comprises a pump driven by a motor, an inverter for controlling the motor, and an accumulator, wherein the inverter controls rotational speed of the motor such that the pump always discharges hydraulic fluid at a fixed flow rate, which is the sum of an average necessary flow rate and an adjustment flow rate, and the accumulator operates, when the fixed flow rate and a necessary flow rate differ, in order to accumulate or discharge the hydraulic fluid to thereby secure the necessary flow rate.

[0012] The accumulator may comprise a plurality of accumulators which differ in accumulation pressure (working pressure) from one another. The plurality of accumulators may be composed of a low pressure accumulator, an intermediate pressure accumulator whose accumulation pressure is higher than that of the low pressure accumulator, and a high pressure accumulator whose accumulation pressure is higher than that of the intermediate pressure accumulator.

[0013] Another aspect of the present invention is to provide a method for controlling a hydraulic circuit which comprises a pump driven by a motor, an inverter for controlling the motor, and an accumulator, the method comprising the steps of causing the inverter to control rotational speed of the motor such that the pump always discharges hydraulic fluid at a fixed flow rate, which is the sum of an average necessary flow rate and an adjustment flow rate; and causing the accumulator to operate, when the fixed flow rate and a necessary flow rate differ, in order to accumulate or discharge the hydraulic fluid to thereby secure the necessary flow rate.

[0014] In an aspect of the present invention, the inverter controls the rotational speed of the motor such that the pump always discharges hydraulic fluid at a fixed flow rate, which is the sum of an average necessary flow rate and an adjustment flow rate, and the accumulator operates, when the fixed flow rate and a necessary flow rate differ, in order to accumulate or discharge the hydraulic fluid to thereby secure the necessary flow rate. Therefore, a flow rate necessary for driving an actuator (necessary flow rate) is secured without fail, and energy can be conserved. Furthermore, since the motor rotates at a fixed rotational speed, it is possible to prevent generation of vibration, which would otherwise be generated because of knocking occurring as a result of low speed operation as in the conventional technique, whereby smooth operation is ensured.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Various other objects, features and many of the attendant advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description of the preferred embodiments when considered in connection with the accompanying drawings, in which:

[0016] FIG. 1 shows a hydraulic circuit according to a first embodiment of the present invention;

[0017] FIG. 2 is a time chart showing the relation between flow rate and time; and

[0018] FIG. 3 shows a hydraulic circuit according to a second embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] For purposes of description herein, the terms “upper,” “lower,” “right,” “left,” “rear,” “front,” “vertical,” “horizontal,” and derivatives thereof shall relate to the invention as orientated in FIG. 1. However, it is to be understood that the invention may assume various alternative orientations, except where expressly specified to the contrary. It is also to be understood that the specific devices and processes illustrated in the attached drawings, and described in the following specification are simply exemplary embodiments of the inventive concepts defined in the appended claims. Hence, specific dimensions and other physical characteristics relating to the embodiments disclosed herein are not to be considered as limiting, unless the claims expressly state otherwise.

[0020] A first embodiment of the present invention will now be described with reference to FIGS. 1 and 2.

[0021] Actuators, for example, cylinders 1A and 1B of a molding machine, each include a piston 1a and a piston rod 1b, and are connected, via changeover means, such as solenoid-operated changeover valves 3, for the cylinders 1A and
1B, to a pipe line R of a hydraulic circuit, such as an oil-hydraulic circuit 5. Furthermore, limit switches LM for detecting stroke ends are provided at opposite ends of the cylinders 1A and 1B.

[0022] A pump 7 and an accumulator 9H are disposed in the pipe line R of the oil-hydraulic circuit 5. The accumulator 9H, whose working pressure is, for example, 13 to 15 MPa, is connected to the pipe line R via a solenoid-operated changeover valve 17. This changeover valve 17 is controlled by an unillustrated control console.

[0023] For example, a no-spring detent-type solenoid-operated valve is used as the solenoid-operated changeover valve 17. This solenoid-operated changeover valve operates as follows. Only when the changeover valve is to be operated, current is supplied to a coil of the valve. After a spool of the valve has moved, the spool engages with a detent and is held at the moved position. A spring urges the detent to enter a groove of the spool. Since the solenoid-operated changeover valve 17 is of an energy conservation type, a higher energy saving effect can be attained.

[0024] The pump 7 is connected to the oil-hydraulic circuit 5, and supplies (discharges) hydraulic fluid within an oil tank 11 to the oil-hydraulic circuit 5. The pump 7 is driven by a motor M, and the rotational speed of the motor M is fixedly controlled by an inverter 13.

[0025] In FIG. 1, reference numeral 14 denotes a pressure switch, 15 denotes a safety valve, 18 denotes a check valve, 19 denotes a drain tank, and 20 denotes a check valve.

[0026] Next, operation of the present embodiment will be described.

[0027] “Determination of Average Necessary Flow Rate”

[0028] The pump 7 is operated so as to discharge the hydraulic fluid within the oil tank 11 to the oil-hydraulic circuit 5, to thereby drive the actuators 1. The quantity Q of the hydraulic fluid discharged from the pump 7 so as to drive the actuators 1 over a single cycle is obtained, and divided by the drive time (the time length of the single cycle) t, to thereby obtain an average necessary flow rate Q1. This average necessary flow rate Q1 is, for example, 30 L/min.

[0029] “Determination of Adjustment Flow Rate”

[0030] An adjustment flow rate a is determined in consideration of fluid leakage of the oil-hydraulic circuit 5. This adjustment flow rate a is an expected rate of fluid leakage, and is set to, for example, 1.5 L/min, which is 5% of the above-mentioned average necessary flow rate Q1.

[0031] “Determination of Fixed Flow Rate”

[0032] A flow rate Q2 obtained by adding the adjustment flow rate a to the average necessary flow rate Q1 is used as a fixed flow rate at which hydraulic fluid is supplied to the oil-hydraulic circuit 5 at all times. Notably, the adjustment flow rate a is equal to a value obtained by subtracting the average necessary flow rate Q1 from the fixed flow rate Q2.

[0033] “Control of the Inverter”

[0034] The inverter 13 determines the rotational speed of the motor M such that the pump 7 can discharge the hydraulic fluid at the fixed flow rate Q2 at all times, and fixes (maintains) the determined rotational speed.

[0035] “Drive of the Actuators”

[0036] The fixed flow rate Q2 is determined in the above-described manner. The inverter 13 determines the rotational speed of the motor M of the pump 7 so as to discharge the hydraulic fluid at the fixed flow rate Q2, and fixedly controls the motor M so as to maintain the determined rotational speed. The solenoid-operated changeover valve 17 for the accumulator 9H is turned on.

[0037] When power is supplied to the inverter 13, the motor M starts to rotate. Since the rotational speed of the motor M is fixed by the inverter 13, the pump 7 discharges the hydraulic fluid into the oil-hydraulic circuit 5 at the fixed flow rate Q2, to thereby drive the actuators 1A and 1B.

[0038] At that time, as shown by a solid line in FIG. 2, the flow rate (necessary flow rate) QX necessary to drive the actuators 1A and 1B changes, with elapse of time t, from Q0 to Q6, then to Q0, then to Q4, then to Q3, then to Q5, and then to Q0. When the necessary flow rate QX is greater than the fixed flow rate Q2 (when the necessary flow rate is between Q6 and Q3), hydraulic fluid is discharged from the accumulator 9H. In contrast, when the necessary flow rate QX is less than the fixed flow rate Q2 (when the necessary flow rate is Q0), hydraulic fluid is accumulated in the accumulator 9H. Through accumulation and discharge of hydraulic fluid by the accumulator 9H, the necessary flow rate QX is secured, whereby the actuators 1A and 1B are driven smoothly.

[0039] Notably, since the rotational speed of the motor is controlled by the inverter 13, even when the hydraulic circuit becomes necessary to be supplied with hydraulic fluid at a different fixed flow rate because of, for example, replacement of actuators, hydraulic fluid can be readily supplied at the desired fixed flow rate by means of changing the rotational speed of the motor through operation of the inverter.

[0040] Next, a second embodiment of the present invention will be described with reference to FIG. 3. Components denoted by the same reference numerals as those in FIGS. 1 and 2 are identical in name and function with those in these figures. The present embodiment differs from the first embodiment in that, in place of the one (single) accumulator, there are provided three (a plurality of) accumulators 9L, 9M, and 9H which differ in working pressure from one another.

[0041] The accumulator 9L is an accumulator for low pressure, and its working pressure is, for example, 10 to 11.5 MPa. The accumulator 9M is an accumulator for intermediate pressure, and its working pressure is, for example, 11.5 to 13 MPa, which is higher than the working pressure of the accumulator 9L. The accumulator 9H is an accumulator for high pressure, and its working pressure is, for example, 13 to 15 MPa, which is higher than the working pressure of the accumulator 9M.

[0042] Next, operation of the second embodiment will be described. The “determination of the average necessary flow rate,” the “determination of the adjustment flow rate,” the “determination of the fixed flow rate,” and the “control of the inverter” are performed in the above-described manner.

[0043] “Drive of the Actuators”

[0044] The fixed flow rate Q2 is determined in the above-described manner. The inverter 13 determines the rotational speed of the motor M of the pump 7 so as to discharge the hydraulic fluid at the fixed flow rate Q2, and fixedly controls the motor M so as to maintain the determined rotational speed. The solenoid-operated changeover valves 17 for the accumulators 9L, 9M, and 9H are turned on.

[0045] When power is supplied to the inverter 13, the motor M starts to rotate. Since the rotational speed of the motor M is fixed by the inverter 13, the pump 7 discharges the hydraulic fluid into the oil-hydraulic circuit 5 at the fixed flow rate Q2, to thereby drive the actuators 1A and 1B.
At that time, the flow rate (necessary flow rate) \( Q_X \) necessary to drive the actuators 1A and 1B changes with elapse of time \( t \). When the necessary flow rate \( Q_X \) is greater than the fixed flow rate \( Q_2 \), hydraulic fluid is discharged from the accumulators 9L, 9M, or 9H. In contrast, when the necessary flow rate \( Q_X \) is less than the fixed flow rate \( Q_2 \), hydraulic fluid is accumulated in the accumulators 9L, 9M, or 9H. Through accumulation and discharge of hydraulic fluid by the accumulators 9L, 9M, and 9H, the necessary flow rate \( Q_X \) is secured, whereby the actuators 1A and 1B are driven smoothly.

Since the accumulators 9L, 9M, and 9H operate in a high pressure range, an intermediate pressure range, and a low pressure range, respectively, as compared with the case where a single accumulator is used solely, energy loss is small, whereby energy can be saved. Furthermore, a pressure switch and a solenoid-operated changeover valve may be provided for each of the accumulators 9L, 9M, and 9H in order to cause the accumulators 9L, 9M, and 9H to operate within the respective pressure ranges only. In this case, a higher energy saving effect can be attained.

In the above, only the preferred embodiments of the present invention have been described. Obviously, numerous modifications and variations of the present invention may occur to persons skilled in the art and persons who make or use the present invention. Therefore, the above-described embodiments shown in the drawings are merely provided for the purpose of explaining the present invention, and are not intended to limit the scope of the present invention, which is defined by the appended claims that are interpreted in accordance with the principle of the patent law, including the doctrine of equivalents.

What is claimed is:

1. A hydraulic circuit which comprises:
   a pump driven by a motor;
   an inverter for controlling the motor; and
   an accumulator,
   wherein the inverter controls rotational speed of the motor such that the pump always discharges hydraulic fluid at a fixed flow rate, which is the sum of an average necessary flow rate and an adjustment flow rate; and
   wherein the accumulator operates, when the fixed flow rate and a necessary flow rate differ, in order to accumulate or discharge the hydraulic fluid to thereby secure the necessary flow rate.

2. A hydraulic circuit according to claim 1, wherein the accumulator comprises a plurality of accumulators which differ in accumulation pressure from one another.

3. A hydraulic circuit according to claim 2, wherein the plurality of accumulators are comprised of a low pressure accumulator, an intermediate pressure accumulator whose accumulation pressure is higher than that of the low pressure accumulator, and a high pressure accumulator whose accumulation pressure is higher than that of the intermediate pressure accumulator.

4. A method for controlling a hydraulic circuit which comprises a pump driven by a motor, an inverter for controlling the motor, and an accumulator, the method comprising the steps of:
   causing the inverter to control rotational speed of the motor such that the pump always discharges hydraulic fluid at a fixed flow rate, which is the sum of an average necessary flow rate and an adjustment flow rate; and
   causing the accumulator to operate, when the fixed flow rate and a necessary flow rate differ, in order to accumulate or discharge the hydraulic fluid to thereby secure the necessary flow rate.